INVESTIGATION AND CONTROL OF MULTILEVEL INVERTERS FOR ELECTRIC VEHICLE PROPULSION

SHORT SYNOPSIS

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DOCTOR OF PHYLOSOPHY

To

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by

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CERTIFICATE

I hereby declare that the short synopsis on "**Investigation and Control of Multilevel Inverters for Electric Vehicle Propulsion**" being submitted in partial fulfillment of the requirement for the degree of Doctor of Philosophy in Electrical & Electronics Department under School of Engineering & Technology of Manav Rachna International Institute of Research & Studies, Faridabad during the academic year 2023-2024.

It is a bona fide record of original work carried out under the supervision of Dr. Richa Adlakha and has not been submitted in full or part to any other university or institute for degree or diploma. Further, it is certified that short synopsis is plagiarism free and proof has been submitted.

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ABSTRACT

The traction inverter is a critical component in electric vehicles (EVs) and plays a crucial role in transforming the battery's DC voltage into AC voltage to control the electric motor. These traction inverters employed in EVs are generally two levels that can be replaced with multilevel inverters. In multi-level inverters, the input DC voltage is divided into different parts thus creating the small levels of the load voltage. This will improve efficiency, reduce electromagnetic interference (EMI), lessen stress on voltage change rate (dv/dt), and better control of electric motor employed in Electric Vehicles.

There are three stages in EV which are batteries, power conditioning unit, and electric motor. The power conditioning unit includes DC-DC converters which are required for the management of charging and discharging of batteries and inverters which are used to control the speed of DC motors. So the Multilevel inverters hold great significance in advanced DC-AC power conversion in EV applications. They have different topologies configurations which provide better efficiency, cost-effectiveness, improved power quality, efficient cooling systems, and fault tolerance. These features make multilevel inverters highly useful in electric vehicles.

For optimum control of converter, the appropriate control technique is necessary, and by controlling the firing angle output voltage can be controlled. Research in this area also involves evaluating the benefits and drawbacks of using high DC link voltages and reviewing the latest topologies used in multilevel inverter design and switching technologies. Additionally, an assessment between two-level and multilevel inverters is being examined to identify their strengths and limitations. The findings of these studies will help determine future requirements for the development of advanced traction inverters for electric vehicles.

KEYWORDS: Traction inverter, Multilevel inverters, Topologies, DC-Link voltages, DC-DC converter, Electric vehicle.

CONTENTS

S. No.	Description	Page No.
1	Introduction	1-3
2	Description of Topic	3-5
3	Literature Review	5-10
4	Research Gap	10
5	Objectives of Research	11
6	Methodology to be adopted	11
7	Expected Outcome of the Research	11
8	References	15-16

INTRODUCTION

The share of India in greenhouse gas emissions is approximately 7.08% of global emission, which is 4th highest in the world [1]. India has few worlds most populated cities as well. On the other side India imports a crude oil in large amount which is a great concern as per energy security for any nation. Economy system is also get affected. So, latest research area to lower down this emission rate of greenhouse gases is Electrical Vehicle. Other reason for the research in field of Electrification of vehicles is declination in earth's natural fuel resources caused in a scarceness in fuel for the power generation. And dependency of a country on few stake holders of crude oil too motivate the researchers to look for sources of energy which would fulfil the human needs and also decrease the damage being done on mother earth. Thus electrical vehicles are considered as the best solution to many issues like scarceness of fuels and emission of greenhouse gases from fuel operated transport. EVs are not only helping in reducing the harmful emission but it has high energy efficiency, acceleration rate is also high and the maintenance required to run is low [2]. But it has few drawbacks also like long charging time, low maximum driving range, which stops it to cover the whole market with electrified transports.

Vehicle operating at high voltage will led to less motor current and thus the efficiency will increase. Because of this benefit many companies are working towards high voltage dc-link feature to their EVs. During the review various features of high voltage dc-link will be discussed along with the challenges for the same. The DC link voltage is an important parameter in multilevel inverters because it determines the number of levels that can be generated by the inverter. In a multilevel inverter, the output voltage is synthesized by connecting multiple power semiconductor devices in parallel-series combination. The level of the output voltage is determined by the voltage supplied to each device. The DC link voltage is the voltage supplied to the inverter from the DC source, such as a battery or rectifier. By switching the power semiconductor devices in a specific pattern, the required output voltage can be generated by DC link voltage [3], [4], [5].

In a multilevel inverter, the output voltage waveform is generated by combining several voltage levels, typically in the form of a staircase waveform. The count of levels that can be

produced is dependent on the DC link voltage. By increasing the DC link voltage, more levels can be generated, resulting in a higher quality output waveform with reduced harmonic content. Thus, the DC link voltage is a critical parameter in the design and operation of multilevel inverters. It is necessary to select an appropriate DC link voltage based on the required output voltage level, the number of levels required, and the operating settings of the system. Every time same topology cannot be used for high voltage. A conventional six switch two-level inverter with 650V switch cannot be used for high voltage. It means we need to change either the semiconductor or inverter topologies. But semiconductor used for high voltage is very costly and switch losses are also more. So the best and economical method is use a different topology ie. go for inverter topology in electrical vehicle instead of changing a semiconductor [6].

Multilevel inverters are commonly used these days in many applications due to their unique features. Their benefits are low voltage stress, less losses in individual semiconductor devices, improved power quality and low electromagnetic interference. A traction inverter also can be designed using a multilevel inverter topology to improve the overall performance of electric and hybrid vehicles [7]. Traction inverter precisely designed for use in electric and hybrid vehicles to convert the DC voltage of the battery into AC voltage to power the electric motor. While a multilevel inverter is a power electronic device that can generate AC voltage with higher quality, lower harmonic distortion, and better efficiency compared to traditional inverters. By using multiple levels of voltage output, the multilevel inverter can produce a smoother output waveform with fewer harmonic distortions, which is beneficial for electric motors that require high-quality power. Usage of multilevel inverter in traction system is the wide area of study.

A survey on different topologies of Multilevel inverter has been carried out. There are several types of multilevel inverters that can be used in electric vehicles. Here are a few examples, A Diode-clamped multilevel inverter which uses a series of diodes to clamp the voltage at different levels, allowing for multiple voltage levels to be achieved without using additional switching components. Second one is Capacitor-clamped multilevel inverter which uses a series of capacitors to clamp the voltage at different levels, providing a higher number of voltage levels than the diode-clamped inverter. Next is Flying capacitor multilevel inverter

which uses a series of capacitors that are switched between different voltage levels, allowing for a higher number of voltage levels and reducing the size of the capacitors needed and the last is Cascaded H-bridge multilevel inverter which has a series of H-bridge modules, each of which can produce multiple voltage levels [8]. By stacking multiple H-bridge modules, a high number of voltage levels can be achieved. All these multilevel inverters have their own pros and cons, and the choice of inverter will depend on the specific requirements of the electric vehicle system. Depending on various topologies, few challenges as well like voltage balancing, use of large no. of semiconductors, capacitors and complex control are there. On basis of application, requirement and load various multilevel topologies are selected [9],[10].

Multilevel inverters are not only required for low power EVs but are useful for high power trains or other high power vehicles. While reviewing various research papers the use of multilevel inverters in traction drives and comparison of topologies in terms of their power quality, price, consistency, power density and efficiency has been inspected. Few constraints and hitches associated with Multilevel inverters are need to discuss. So that work on scope of improvement in performance and efficiency can be done.

DESCRIPTION OF BROAD AREA

A Multilevel inverter is a power inverter used to convert direct current (DC) into alternating current (AC) at different voltage levels. Unlike traditional two-level inverters, which switch between full DC voltage and zero volts, multilevel inverters generate AC output by synthesizing the voltage using multiple levels or voltage steps. This results in a stepped waveform with a closer approximation to a pure sine wave, and it offers several advantages in terms of efficiency, voltage quality, and reduced harmonic distortion. These inverter provides the solution for achieving high power capabilities with the use of multiple switching devices. A n-level inverter will be able to reproduce n levels of voltage. The main principle of a multilevel inverter is to use a combination of semiconductor devices (usually Insulated Gate Bipolar Transistors or IGBTs) and voltage accumulation capacitors or o ther electronic sources to create multiphase AC output waveforms. The basic concept involves dividing the output voltage into several discrete levels, typically in a staircase-like fashion which leads to the desired form. They are capable of driving the high power vehicles

and ideal ac voltage can be achieved by increasing the number of steps which leads to minimum total harmonic distortion.

Commonly used topologies of Multilevel inverter includes diode-clamped (Neutral-Point Clamped) Inverter, Flying Capacitor, and H- Bridge Inverters. This topology uses capacitors connected to the midpoint of the DC bus to create multiple voltage levels. It is also known as a flying capacitor inverter. Other is Cascaded H-Bridge Inverter- In this configuration, individual H-bridge modules are connected in series to achieve multiple voltage levels. Each H-bridge module can independently control its output voltage.

Their ability to reduce harmonic distortion, improve voltage quality, and handle high voltages makes them a valuable component in modern power electronics systems across various industries like Renewable energy systems (solar and wind inverters), Electric vehicles (motor drives), High-voltage DC (HVDC) transmission systems, Uninterruptible power supplies (UPS), Energy storage systems (battery inverters), Rail transportation (traction systems), Power quality improvement (active filters), Grid integration of distributed generation sources, Custom power electronics for specialized applications.

Multilevel inverters are considered these days due to their ability to address numerous challenges related with EV propulsion systems, including efficiency, power quality, and thermal management. Here is an overview of the key advancements and benefits of multilevel inverters for electric vehicle propulsion:

i. **Improved Efficiency**: Multilevel inverters are known for their ability to operate at higher voltages, which reduces the current flowing through the power electronic components. This leads to lowering the switching losses and, consequently, enhance the overall efficiency in the power conversion process. Higher efficiency means longer driving range for EVs on a single battery charge.
ii. **Enhanced Power Quality:** Multilevel inverters generate advance-quality output voltage waveforms as compare to previously preferred two-level inverters. This improved power quality reduces electromagnetic interference (EMI) and ensures smoother operation of the electric drive system. This is crucial for maintaining the

reliability of sensitive on-board electronics and reducing wear and tear on the vehicle's components.

iii. **Reduced Harmonics:** Multilevel inverters inherently produce fewer harmonics in the output voltage, which contributes to cleaner power delivery to the electric motor. Reduced harmonics result in less stress on the motor and contribute to longer motor life.

iv. **High Voltage Operation:** Electric vehicle batteries often operate at high voltage levels. Multilevel inverters can be designed to match these high-voltage requirements without the need for additional voltage-boosting stages. This simplifies the overall powertrain architecture and reduces the number of components, which can lead to cost savings and increased reliability.

v. **Generative Braking:** Multilevel inverters can facilitate regenerative braking more effectively by controlling the flow of energy between the electric motor and the battery. This feature increases energy efficiency and extends the vehicle's range by converting kinetic energy back into electrical energy during braking.

vi. **Thermal Management:** Electric vehicles require effective thermal management systems to dissipate heat generated during power conversion. Multilevel inverters, due to their reduced switching losses, generate less heat compared to traditional inverters, making it easier to manage temperature in the power electronics.

vii. **Research & Development:** Ongoing research and development efforts in the field of multilevel inverters are leading to the development of novel topologies and control strategies, further enhancing their performance, efficiency, and reliability for electric vehicle propulsion. As the EV market endures to grow, multilevel inverters are likely to play an important role in improving the performance and range of electric vehicles while diminishing their environmental effect.

LITERATURE REVIEW

Multilevel inverters have achieved significant attention in recent years due to their prospective to improve the performance of electric vehicles. They have many advantages over traditional two-phase inverters, including improved voltage quality, increased efficiency and reduced

harmonic distortion.

The paper [11] highlights the benefits of upgrading the voltage power for battery-electric passenger vehicles to 800 volts (V) and its implications for the electric vehicle industry. The paper discussed the current state of the electric vehicle industry and the challenges it faces, including range anxiety, high costs, and long charging times. It then introduces the concept of 800-V systems and explains how they can address some of these challenges. The authors argue that upgrading the voltage power for battery-electric passenger vehicles from the standard 400 V to 800 V can improve vehicle performance, reduce charging times, and lower costs. The paper goes on to discuss the technical aspects of 800-V systems, including their impact on battery performance, electric motors, and power electronics. It also describes how the higher voltage can enable faster charging times, improve regenerative braking, and reduce the weight and complexity of the vehicle's electrical system. The authors then present a case study of the Porsche Mission E, a high-performance electric vehicle that uses an 800- V system. The case study highlights the benefits of the 800-V system, including a longer range, faster acceleration, and shorter charging times. The paper concludes by discussing the potential challenges of implementing 800-V systems, including the need for new infrastructure, the cost of the technology, and the potential safety risks. Overall, this research paper provides a good review of the literature on the benefits of increasing the electric passenger vehicle voltage to 800V and its impact on the electric vehicle industry. The authors present a compelling case for the adoption of 800-V systems, and the case study of the Porsche Mission E demonstrates the potential of this technology to improve vehicle performance, reduce charging times, and lower cost.

In the paper [12] the author discussed the latest DC-DC power level topology and control techniques for external charger. Various methods such as soft switching, interfacing, and switching to improve the efficiency and effectiveness of these power stages were also discussed.

A review of multilevel converter topologies and a new multilevel converter topology based on the cascaded connection of elementary units is introduced in the paper [13]. The introduction of this article highlights the importance of high energy products in high energy applications such as renewable energy systems and electric vehicles. The author explains that multilevel converters can provide good power while minimizing the difference between spin and

conversion. The literature review section of the paper presents a detailed analysis about the developed high power application of multilevel converter topologies. The authors discuss the pros and cons of various multilevel converter topologies, such as diode-clamped, flying capacitor, and cascaded H-bridge inverters. The comparison has been done on basis of efficiency, power quality and reliability of any converter. This paper presents a new multilevel converter topology based on cascade connection of basic cells. The author explain that this new topology can deliver more power while reducing the number of components required compared to existing multiphase converter topologies. The paper also highlights some of the key design considerations for multilevel converters, such as modulation techniques, control strategies, and thermal management. The authors discuss various modulation techniques for multilevel converter, including pulse width modulation (PWM), space vector modulation (SVM), and selective harmonic elimination (SHE). They also explain how the control strategies for multilevel converters can be optimized for different applications and operating conditions. Finally, the conclusion section of the paper summarizes the key findings of the literature review and introduces the new generalized multilevel converter topology. The authors emphasize the importance of developing multilevel converters that are highly efficient, reliable, and cost-effective for high-power applications. They suggest that future research should focus on improving the performance of existing multilevel converter topologies and designing new topologies to meet the growing demand for power supplies that are good for high-power applications. Overall, this article provides a comprehensive literature review on multilevel converter topologies and introduces a new generalized multilevel converter topology based on the cascaded connection of basic units. The authors provide detailed information on various switch topologies and highlight the important design points to consider when designing efficient, reliable, and robust

switches.

A comprehensive review of multilevel inverter (MLI) topologies in electric vehicles also has been studied distinctly [14]. The authors begin by discussing the importance of MLIs in electric vehicles, highlighting their ability to reduce the size and weight of the power electronic system and increase the efficiency of the vehicle. They then provide a detailed description of the different MLI topologies, including diode-clamped, capacitor-clamped, and cascaded H-bridge inverters. This review paper also explains the numerous modulation techniques used in MLIs,

including space vector modulation, selective harmonic elimination, and phase-shifted pulse width modulation. The authors discuss the gain and shortcomings of each technique with examples of their application in electric vehicles. Additionally, the paper highlights the challenges and future directions in MLI research for electric vehicles. These include improving the efficiency and power density of the MLIs, reducing their cost, and developing new control techniques. So, precisely this article provides a comprehensive literature review of the current status and future trends of MLI topologies in electric vehicles. A valued resource for intellectuals and engineers working in the field of electric vehicle power electronics is obtained [15]. Various topologies along with the challenges of two level inverters has been discussed.

The author provides a comprehensive review of the recent advancements in DC-DC converter topologies for light electric vehicle charging. The introduction section of the paper presents an overview of the current status of electric vehicle and the significance of DC-DC converters in the charging process. The authors explain that DC-DC converters play an important role in setting the voltage and current levels required to charge an electric vehicle. The literature review section of the paper presents a detailed analysis of various DC-DC converter topologies that have been developed for light electric vehicle charging. The authors categorize the converters into two main categories: isolated and non-isolated converters. For each category, the authors discuss the pros and cons of various converter topologies. The paper also highlights some of the key design considerations for DC-DC converters, such as efficiency, size, and cost. The author discusses various techniques to improve DC-DC converter efficiency, including zero voltage conversion, zero current conversion. They also explain how the size and cost of DC-DC converter can be reduced by using advanced

semiconductor materials and magnetic materials. Finally, the conclusion section of the paper summarizes the key findings of the literature review and provides some recommendations for future research. The authors emphasize the importance of developing DC-DC converters that are highly efficient, compact, and cost-effective for light electric vehicle charging. They suggest that future research should focus on developing new converter topologies and improving the performance of existing ones. Overall, the paper delivers a comprehensive review of the recent advancement in DC-DC converter topologies for light electric vehicle charging. The authors present a detailed analysis of various converter topologies and highlight the key design considerations that need to be taken into account for developing efficient,

compact, and cost-effective converters. [16]

The design and performance of multilevel inverters for electric vehicles has been discussed [17]. The introduction section of the paper provides a summary of the significance of multilevel inverters in electric vehicles. The authors explain that multilevel inverters are required to provide high-quality power to electric vehicles, which is essential for their reliable and efficient operation. The literature review section of the paper provides a detailed analysis of various multilevel inverter topologies that have been developed for electric vehicles. The authors discuss the pros and cons of various multilevel inverter topologies, such as diode-clamped, flying capacitor, and cascaded H-bridge inverters. They also relate these topologies in terms of reliability, power quality and efficiency. The paper highlights some of the key design considerations for multilevel inverters, such as modulation techniques, control strategies, and thermal management. The authors discuss various modulation techniques for multilevel inverters, including pulse width modulation (PWM), space vector modulation (SVM), and selective harmonic elimination (SHE). They also explain how the control strategies for multilevel inverters can be optimized for different applications and operating conditions. Finally, the conclusion section of the paper summarizes the key findings of the literature review and provides some recommendations for future research. The authors emphasize the importance of developing multilevel inverters that are highly efficient, reliable, and cost-effective for electric vehicles. They advise that future investigation should focus on enhancing the performance of present multilevel inverter topologies and developing new ones that can meet the growing demand for high-quality power in electric vehicles.

Overall, the article delivers a comprehensive review of the design and performance of multilevel inverters for electric vehicles. The authors present a detailed analysis of various multilevel inverter topologies and highlight the key design considerations that need to be taken into account for developing efficient, reliable, and cost-effective inverters.

In the article Modelling of Electric Vehicles with MATLAB/Simulink by Al Halabi, M. and Al Tarabsheh, A. (2020), the authors present a MATLAB/Simulink model of electric vehicles. The simulation process was carried out using MATLAB code and Simulink models. Benefit of defining the model is that aerodynamic drag, linear acceleration and rolling resistance are simulated. Other benefits include traction effects, engine performance and battery life. [18],[19].

Overall, the literature suggests that multilevel inverters have great potential for use in electric vehicle applications, particularly in high-power applications such as electric buses. Though, the selection of inverter topology will depend on a number of parameters, including performance requirements, cost, and operating conditions. Further research is needed to optimize the design and control of multilevel inverters for electric vehicle applications.

RESEARCH GAPS

1. Power Density Optimization: Research can focus on developing advanced circuit topologies, progressive semiconductor devices, and packaging techniques to achieve higher power density without affecting efficiency and reliability. The design of compact and lightweight multilevel inverters is crucial for EVs with restricted space and weight restraints.
2. Cost Reduction Strategies: The cost of multilevel inverters is still relatively high in comparison with traditional inverters, which can affect the affordability and mass acceptance of electric vehicles.
3. Consistency and Fault-Tolerant Operation: Consistency is a critical aspect of EV power electronics systems, including multilevel inverters. Enhancement is required in the field of developing advanced fault detection and diagnostic practices, robust protection tools, and fault-tolerant control approaches to ensure nonstopable operation and minimize downtime.
4. Dynamic Performance and Transient Response: Development in progressive control algorithms, modulation strategies, and energy management methods is required to improve the dynamic response, torque control, and overall performance of multilevel inverters in electric vehicles.
5. Integration with Energy Storage Systems: Advancement in the optimal integration techniques, control strategies, and energy management algorithms is must to leverage the potential synergies between multilevel inverters and energy storage systems, thus the energy utilization and EVs performance will be enhanced
6. Real-World Endorsement and Field Testing: While simulation studies and laboratory prototypes provide valuable insights, there is a need for real-world validation and field testing of multilevel inverters in actual electric vehicle applications. Comprehensive

field trials and long-term durability studies are necessary to evaluate the performance, consistency, and efficiency of multilevel inverters under real-world driving conditions, varying loads, and temperature extremes.

OBJECTIVES OF RESEARCH:

1. To conduct a literature review on the technologies related to electric vehicles.
2. To engage in the modeling and simulation of electric vehicle systems.
3. To scrutinize conventional inverter topologies with a focus on control strategies and their suitability in electric vehicle, considering the need for filters.
4. To evaluate artificial intelligence-based controller for their applicability in electric vehicles.
5. To perform an economic assessment of electric vehicle technology.

METHODOLOGY TO BE ADOPTED

Subsequent steps to be adopted to convey the research work

1. Evaluating current electric vehicle technology and exploring the most recent industry trends.
2. Creating models by MATLAB simulation to simulate the electric vehicle drivetrain.
3. Conducting comparative simulations of traditional multilevel inverter configurations for electric vehicles.
4. Implementing AI-based control techniques on multilevel inverters using Fuzzy logic toolbox and deep learning toolbox of MATLAB.

PROPOSED OUTCOME OF THE RESEARCH

1. The multilevel inverters are famous for reduced harmonic distortion which lead to produce a good quality voltage waveform.
2. The proposed research can help to build a design which is useful for power conditioning and better efficiency.
3. With the new design fault tolerance can be boosted so that during fault conditions system keeps on operating successfully.

4. By exploring new designs manufacturing cost can be reduced.

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by Shweta Bhardwaj

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